sMDT muon chambers WBS 6.6.y.5

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U.S. ATLAS HL-LHC Upgrade NSF Conceptual Design Review

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sMDT experts

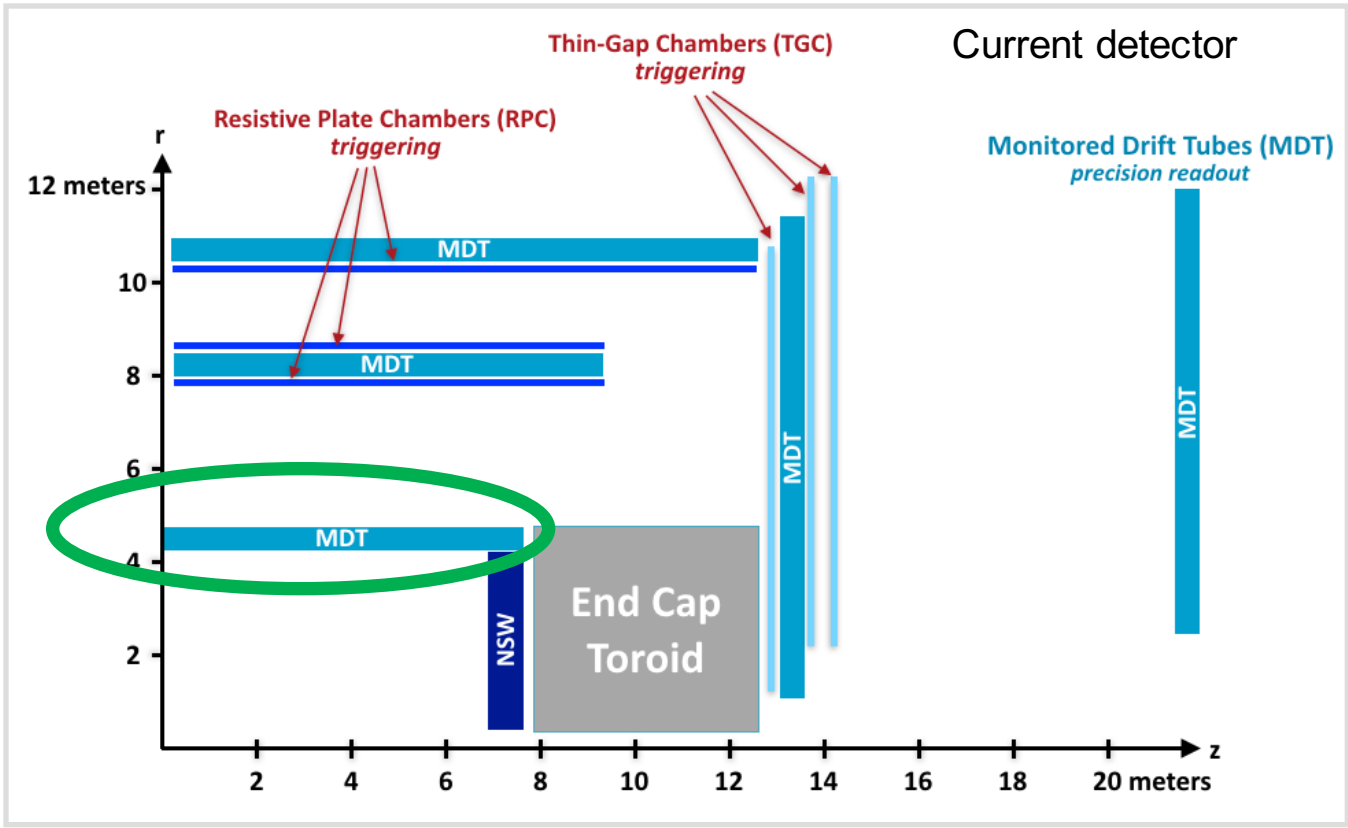
- Reinhard Schwienhorst, WBS 6.6.5.5
  - Associate Professor, Michigan State University
  - L3 manager for Phase 1 upgrade project: L1 Calorimeter trigger fiber plant
- Bing Zhou, 6.6.3.5
  - Professor, University of Michigan
  - The US ATLAS project leader for the current ATLAS MDT detector construction, commissioning and operations
  - The U of M project leader for design and construction of 32,000 tubes and 80 largest MDT chambers for the current ATLAS Muon Spectrometer

Institutes

- Michigan State University, WBS 6.6.5.5
  - Experienced electronics engineers
  - Experience in large construction projects
    - Tile calorimeter modules for ATLAS
    - Fibers for Nova neutrino experiment
    - Many others
- University of Michigan, 6.6.3.5
  - Long experience in muon detection
  - Room, granite table, infrastructure in place from MDT construction

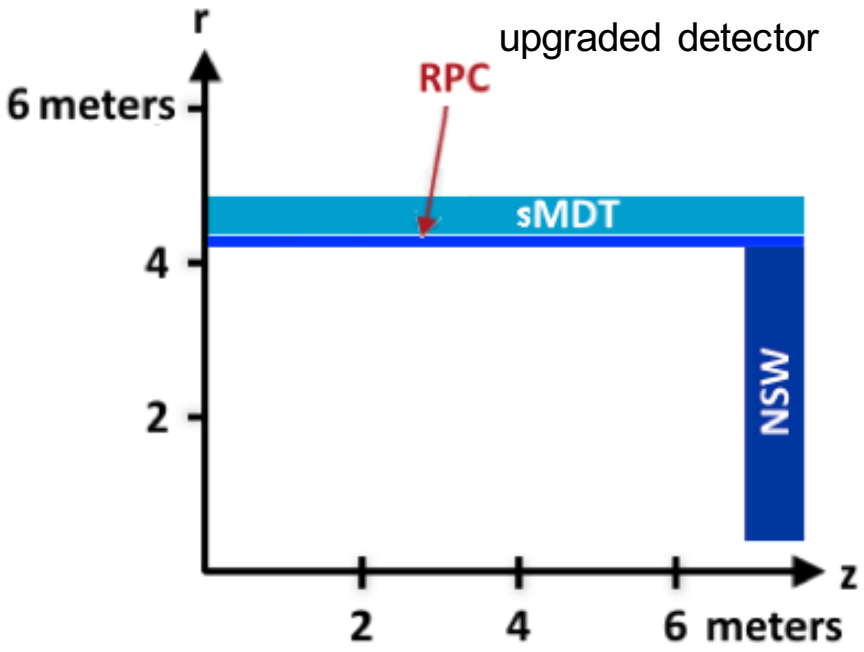
Introduction

- Replace monitored drift tubes (MDT) chambers in inner barrel of muon spectrometer with small-MDT (sMDT) and RPC
  - allow for 3 station MDT trigger to improve trigger p_T resolution
  - increase barrel trigger efficiency from 65% to 95%
  - Crucial for HL-LHC physics program
- As part of improvements to muon trigger
  - Allow single-muon triggers at 20 GeV
  - Allow di-muon triggers at 10 GeV



sMDTs

- Inner barrel MDT chambers are replaced by sMDT
- First ¼ of sMDT chambers will be installed in Phase-1
- Other ¾ of sMDT chambers will be installed in Phase-2



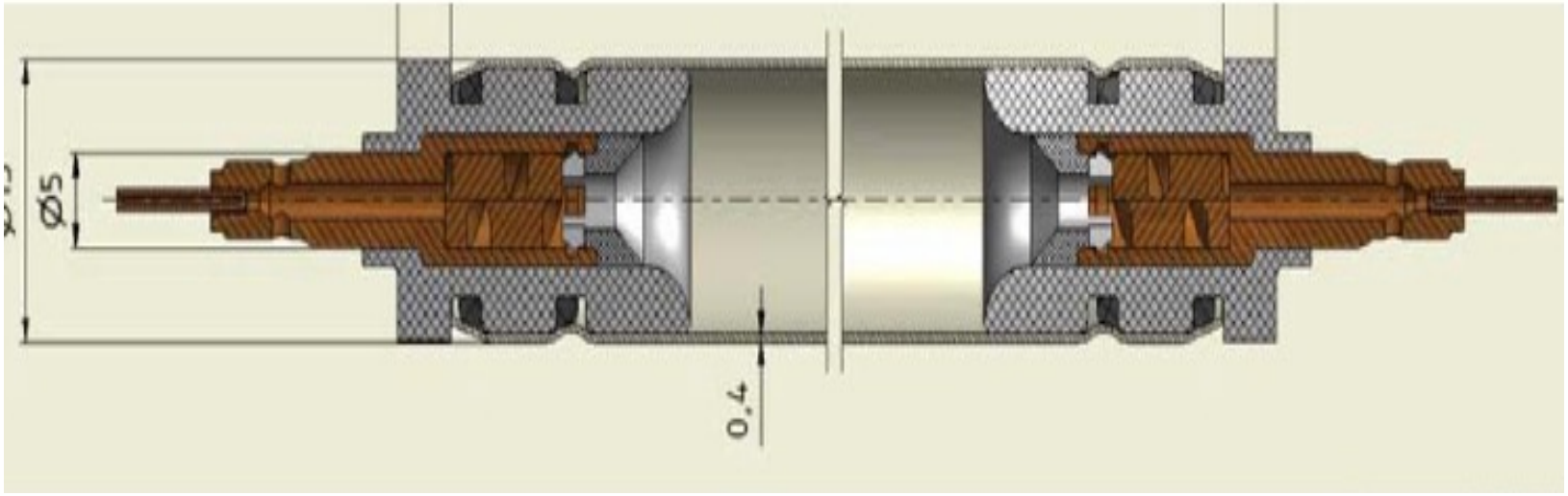
ATLAS sMDT upgrade

- Total: 48,000 tubes in 96 chambers
  - Half built at MPI in Munich, Germany with help from Protvino, Russia
  - Half built in US
- WBS 6.6.5.5: tube construction
  - In a clean room in HEP area at Michigan State University
  - By MSU HEP engineers and technicians
  - 25,000 tubes, incl. 5% overage
- WBS 6.6.3.5: Tubes assembled into chambers
  - In existing facilities at University of Michigan
  - By U of M HEP engineers and technicians
  - 48 chambers assembled and tested
- Close cooperation and coordination between the two institutes

WBS 6.6.5.5 – sMDT tubes

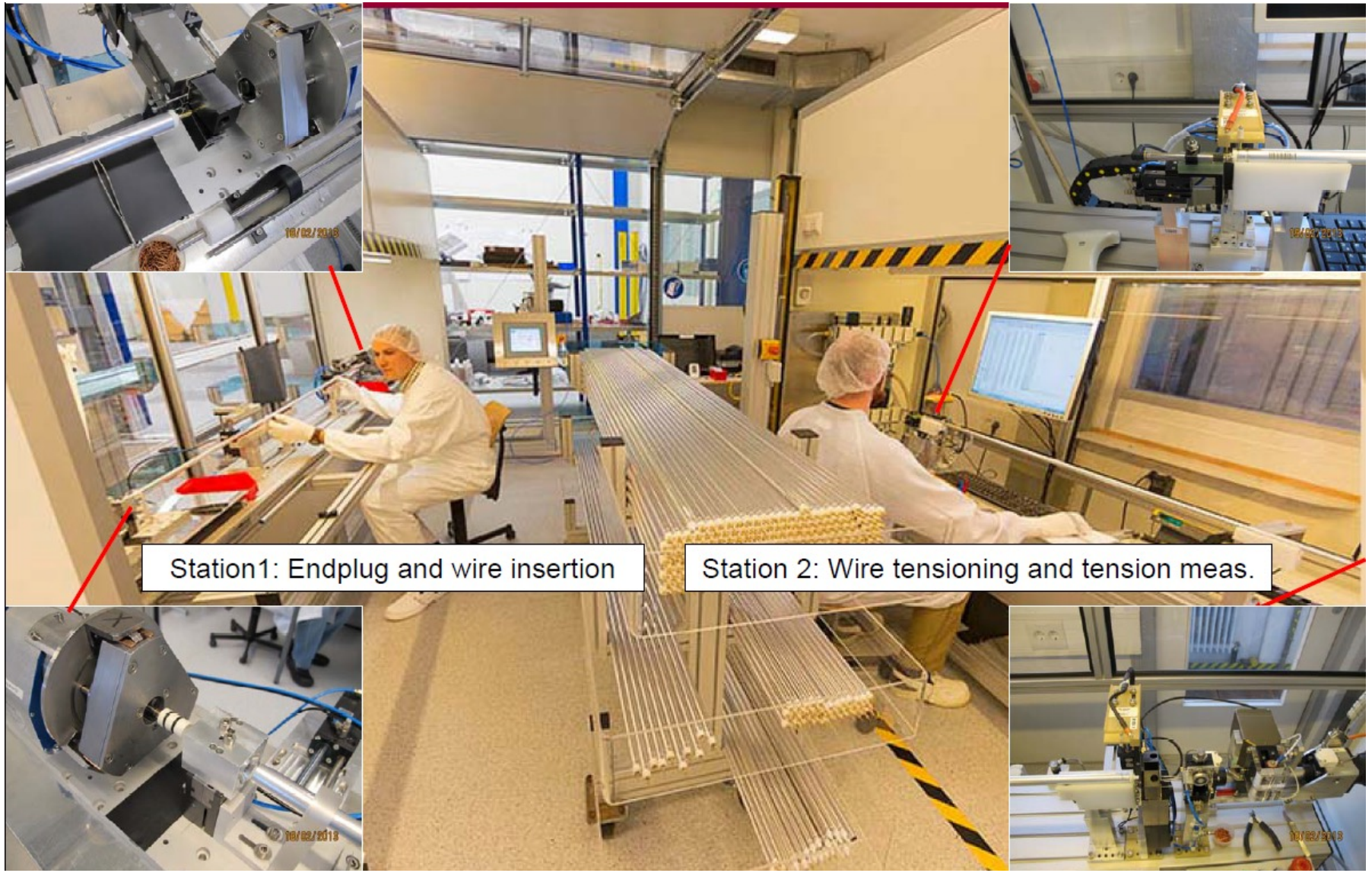
- Fabrication and assembly and testing of 25,000 sMDT tubes
  - Granite table for assembly
  - Automatic wiring station
  - Wire tension, tube leak and dark current test stations
- Tube production from April 2020 to Sept 2022
  - On average, build 50 tubes per day
  - 4.5 FTE total
  - Shipping tubes to University of Michigan

sMDT tubes



- Each tube 1.5 cm diameter, 1.67 m length
- Thin-wall (0.4mm) aluminum tube, wire 50 micron diameter, 2 precision end-plus, two precision wire-locator (twisters), 4 radiation-hard o-rings, two signal pins, and two signal caps
  - Purchasing through CERN in cooperation with MPI and Protvino

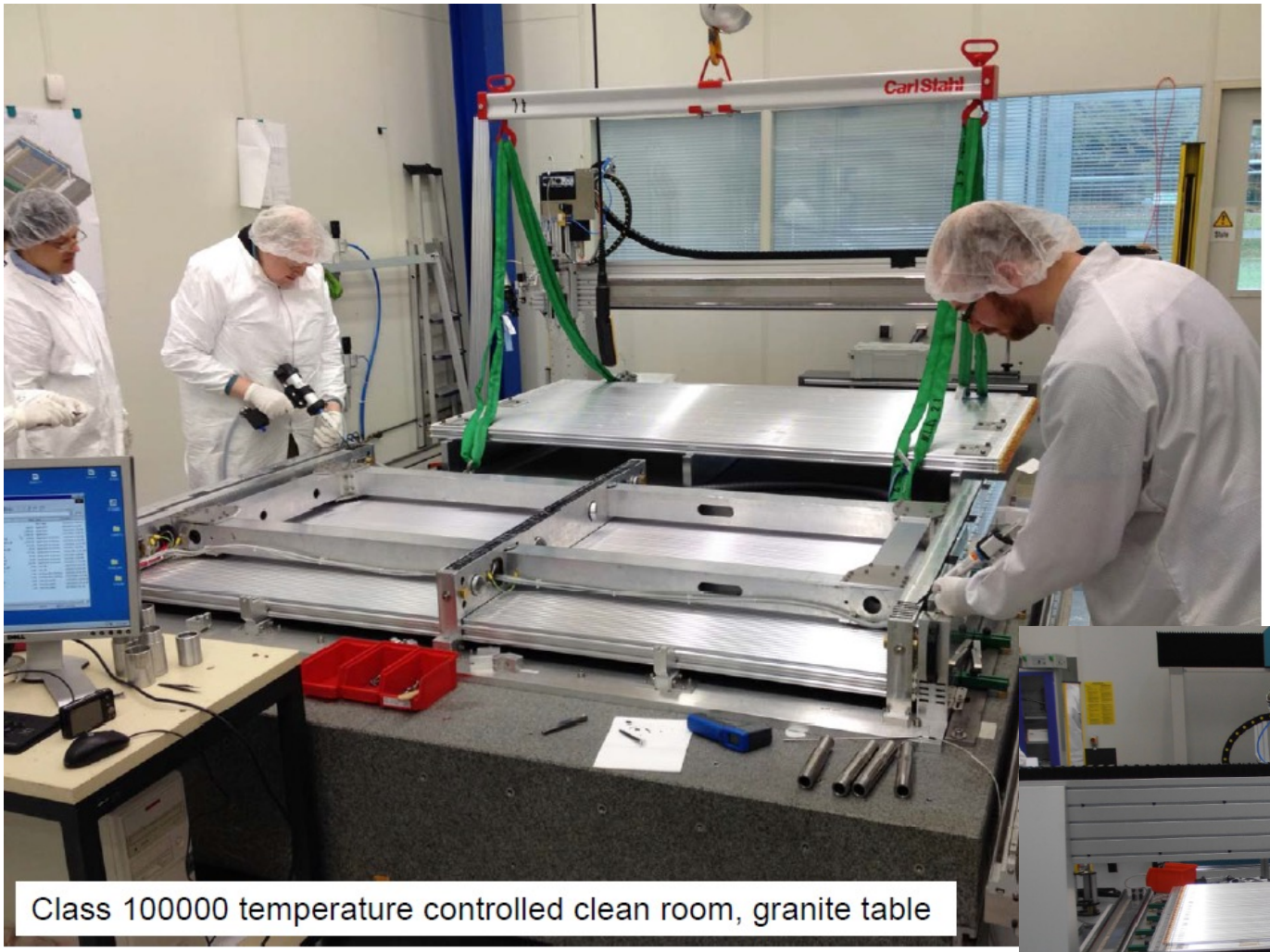
sMDT tube construction facilities at MPI



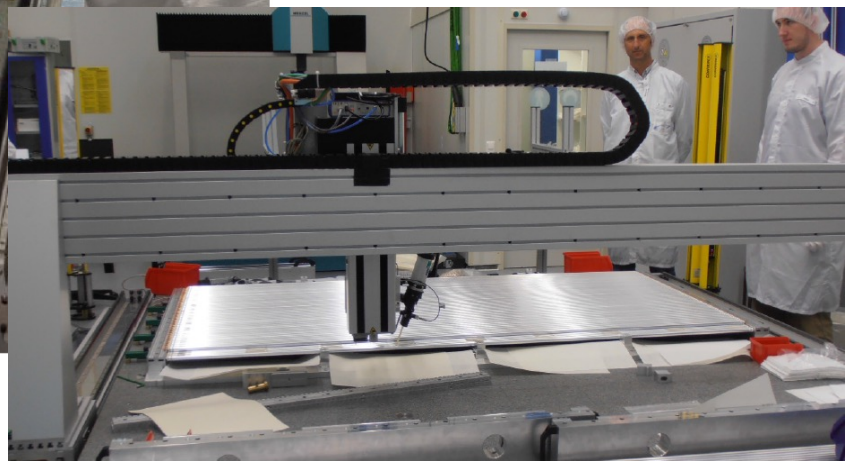
WBS 6.6.3.5 – sMDT chambers

- Assembly and testing of 48 sMDT chambers
  - Chamber assembly precision jigging on granite table
  - Precision spacer assembly station
  - Gas assembly and test station and electronics (HV and RO) test station
  - Design of the mechanical structure for chamber mounting and integration with RPC as well as for alignment device installation mounts.
- Chamber production from July 2020 to December 2022
  - 9 FTE total
  - Ship chambers to CERN

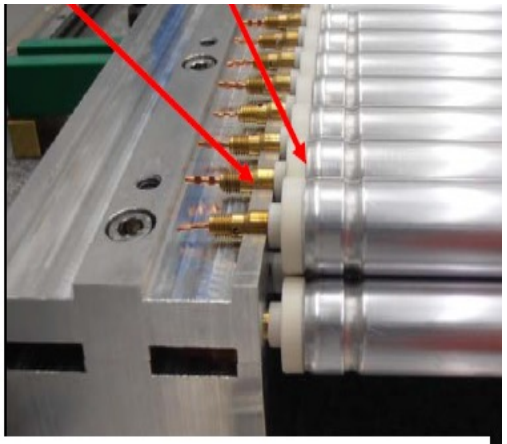
sMDT chamber construction facility at MPI



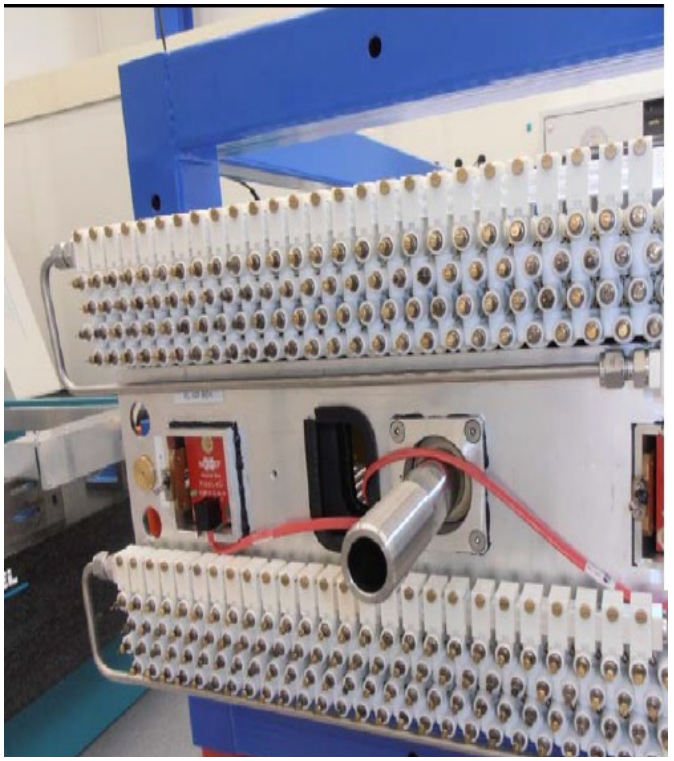
Class 100000 temperature controlled clean room, granite table



sMDT chambers



Drift tube and sense wire positioning using external reference surface of endplugs



- Build the precision spacer frame
- Glue two multi-layer tubes to the space frame
- Mount the alignment sensors and install gas and HV/RO systems
- Test stations for tube location precision, gas manifold, HV, and electronics

Development

- Pre-construction is required in FY 2019
- MSU:
  - Set up clean room
  - Set up table and tooling
- University of Michigan:
  - Room and table already in place
  - Set up tooling
- Both institutions:
  - Set up testing stations
  - Fabricate model-0 tubes
  - Assemble and test model-0 chamber

Budget estimation

- Material estimate based on previous purchases for MDT construction and on existing purchases at MPI Munich
- Engineering and technician estimate based on experience with MDT construction at University of Michigan and sMDT construction at MPI Munich

Tube construction cost

construct of 25000 tubes (with spares)		on average build and test 50 tubes per day.
Materials for tube assembly		
Al tubes	25000 tubes (8/tube)	200,000
Wire	1000/km	41,500
end-plug	50000 (7.2/unit)	360000
Total		601,500
other M&S for clean room		25,000
Manpower	Two FTE each year for 27 month	
Mech Tech	2.0 FTE	172,579
IDC/year		94,919
Salary, bnefit, IDC/year		267,498
For 27 month (2.25 year)		601,870
Travel		18000
Total cost for tube construction		**1,246,370**

Chamber construction cost

Chamber construction		cost for
Manpower	FTE/year	27 months
Mech Eng	0.5 FTE	157,040
Elec Eng	0.5 FTE	147,760
Mech tech	2.0 FTE	506,590
Eng student	2.0 FTE	126,650
construction manpower		938,040
M&S		
Gas connectors		90,720
Spacer/support		50,400
Faraday Cages		25,200
Gas distribution		20,160
Alignment parts		20,160
Tranport tools		25,200
HV/RO distribution		228,413
Total Core cost		460,253
M&S (glue and so on)		50,000
Travel		18,000
Chamber construction		1,466,293

Risk

- No specific risk associated with sMDT deliverable
- Affected by global risk on currency exchange rate fluctuations

Closing remarks

- sMDT construction is rquired to enable Phase-2 muon trigger upgrades
- 25,000 tubes to be constructed at MSU
  - $1,246k
- Assembled into 48 chambers at U of M
  - $1,246k
- Self-contained project

Additional Material

Motivation and Scope of Building sMDT

- In order to keep high trigger efficiency (>90%) for Muon Spectrometer, an inner layer RPC detector must be added to Barrel Inner layer of the Muon Spectrometer
- To fit the RPC into the existing small space, MDT chambers must be replaced by small-tube MDTs for BIS chambers
- **The scope of the task**
  - total **48,000** drift tubes (diameter=1.5 cm, and length = 1.67m)
  - Assembled tubes into **96** sMDT chambers
  - US will build half of the system (i.e. 24,000 tubes, and 48 chambers) by MSU (for tubes) and UM (for chambers)
  - We will be in close collaboration with MPI and Protvino (Russian group) for the sMDT construction project

Material purchases

- A lot of R&D was carried out when building the current muon MDT chambers to find qualified company who can provide high quality (tube wall thickness uniformity better than 10%, straightness better than1%, and well defined the tube clean procedure. We tested tubes from five different companies (including one from US) worldwide and selected one from Switzerland. The same situation for end-plugs and wire locator (twister), wire-pin and O-ring.
- Identifying US companies for these specialized precision, clean tubes, end-plus (radiation hard material, no out-gassing, no cracks under tube crimping pressure) would require intensive R&D, which would cost a lot more time and funds

Tube pre-construction cost

Tube tooling cost estimation	Cost	Comment -- need one year
1) Wiring table (12 feet x 4 feet)	3000	Shipping from UM
2) clean flowbox(2)	24,000	purchase
3) mechanical tube crimping device (2)	4,000	purchase
4) Wire pin crimping tool (2)	4,000	purchase
5) Auto-wiring tension system	5,000	build
6) Tension test station	3,000	build
7) Leak detector	22,000	purchase
8) dark current test station	10,000	build
9) Mech structures on wiring table	15,000	build
10) gas system for leak test (flow meters…)	10,000	build
11) module 0 tubes and parts (650 tubes)	12,000	construction
12) other M&S (cealn cloth, shoe, and pads)	8,000	purchase
Total tooling cost	120,000	
Manpower to build and test the tube assembly:		
Mech engineer (1 FTE, Shooltz)	78,020	Mech design and set up of the tooling
Elec. Engineer (0.5 FTE)	51,500	write software for auto wiring, test stations
Mech. Tech. (1 FTE, Nila)	50,690	Assist to build the wiring stations, Mod 0 tubes, and test them
Total manpower for tooling	180,210	
Travel	3,000	
Total cost for pre-construction	**303,210**	

Chamber pre-construction

Chamber tooling	(Construction tooling, one year, build/test Mod 0, 3 month, including review)			
Set up assembly room and tables		1 month	10,000	temp./humidity control system
Design and produce the chamber assembly jigging		3 month	40,000	design and machining (2 sets)
Design and build the gluing machine, test		2 month	100,000	purchase/build
Install the tooling on granite table, and measurement tool		1 month	10,000	machining
Precision measurement tooling and test/software		1 month	50,000	Purchase
Design and construct the chamber handle carts		2 month	10,000	build
Design and construct the gas manifold		1 month	10,000	
design the HV test electronics boards and set up test stations		2 month	10,000	
design and construct the gas test stations		2 month	5,000	Leak detector will need to be maintained
design and construct the cosmic ray test station		3 month	10,000	
design the shipping boxes and protocol		1 month	5,000	
Design and produce spacer frame (mod 0)		1 month	8,000	
Design and produce gas manifold, parts (mod 0)		3 month	4,000	
Design and build the gas connection parts clean bath		2 weeks	2,000	
Design and build FC (Mod)		1 month	3,000	
Build Mod 0 (with clean room M&S, glue, mixing…)			3,000	
Tooling cost			280,000	
Manpower	15 month	(1.25 year)		
Mech Eng (1 FTE)	186,190			
Electric Eng (0.1 FTE)	15,883			
Mech Tech (1.4 FTE)	190,996			
Eng. Student (0.25 FTE)	13,614			
manpower for tooling	406,683			

Details of the Base Estimate (Explanation of the Work)

This BOE covers the production of 50% of the sMDT chambers needed for the Muon Spectrometer phase II upgrade to add the Level-1 trigger device in the barrel inner station of the Muon Spectrometer. The effort includes fabrication of assembly and test stations for tube and chamber constructions, purchasing precision tubes and end-plugs and other components needed for construction tasks, making total 24000 tubes and assemble these tubes into 48 chambers, shipping of the complete sMDT chambers to CERN in early 2023 for integration with RPC and pre-commissioning prior to installation in ATLAS pit in 2024.

Labor for pre-production (tooling and model-0)

1) **Pre-production**: build the **tube** and **chamber** assembly and test stations and produce module-0 to certify the precision and procedure for construction tasks.
   a. Will need labor for tube pre-construction: 1.0 FTE mechanical engineer, 1.0 FTE mechanical technician and 0.5 FTE electrical engineer for 12 months in 2019 – to build the automatic wiring station, and the wire tension, tube leak and dark current test stations
   b. Will need labor for chamber pre-construction: 1.0 FTE mechanical engineer, 1.0 FTE mechanical technician and 1.0 FTE electrical engineer for 15 months in 2019 – 2020 – to build the automatic gluing machine, the chamber assembly precision jigging on granite table, the precision spacer assembly station, the gas assembly and test station, and electronics (HV and RO) test station. In addition, design the mechanical structure for chamber mounting and integration with RPC as well as for alignment device installation mounts.

2) Labor sMDT construction

a. Construction and test total 25000 tubes (with 5% spares) starting from April, 2020 and finish by Sept. 2022 requesting total 4.75 FTE mechanical technician support. Assuming on average constructing and test 50 tubes each day. The task will need 1.0 FTE for tube assembly and 1.0 FTE for tube tests (wire tension, leak and dark current). Faculty member will need to provide supervision for construction and testing.

b. Construction and test total 48 sMDT chambers in 27 months starting from July 2020 and finish by Dec. 2022. All the sMDT need to be shipped to CERN by the end of 2022. Assuming on average constructing and test one chamber (gluing 8 layers of tubes and a precision spacer frame) every two weeks. In addition, the different types of spacer frames need to be designed and fabricated, as well as the gas system and HV and RO distribution boards, and the FC must be installed on chamber and perform gas leak and HV tests for each chamber. The task will need 0.5 FTE mechanical engineer, 0.5 FTE electric engineer, 2.0 FTE mechanical technician and 1.0 FTE engineer student for 27 months. Faculty member will need to provide supervision for construction and testing.

The needed labor FTEs are based on experience with the MDT tube and chamber constructions for Run 1 muon detector at the University of Michigan, as well as the sMDT construction experience at MPI (Germany) for muon detector Phase I upgrade project.

Summary Labor for sMDT construction: (total 13.75 FTE)

Total 4.75 FTE of Mechanical Technician for tube assembly and test

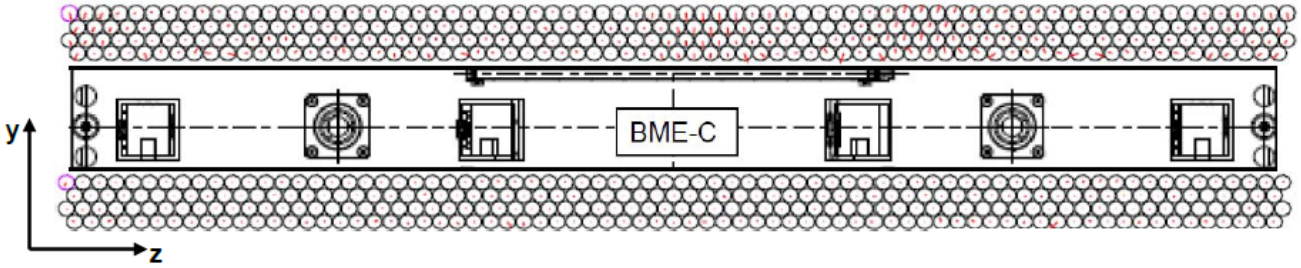
Total 9.0 FTE (1.125 M.E., 1.125 E.E., 4.5 M. Tech. and 2.25 E. student)

Engineering support

- Mechanical engineer at University of Michigan is Curtis Weaverdyck and electric engineer is Jon Ameel, they are experienced engineers with MDT construction and test. They will be available and re-direct their effort on sMDT project in 2018.
- Mechanical engineer at Michigan State University is Dean Shooltz. He has experience in ATLAS tilecal electronics, but also in previous ATLAS and other construction projects

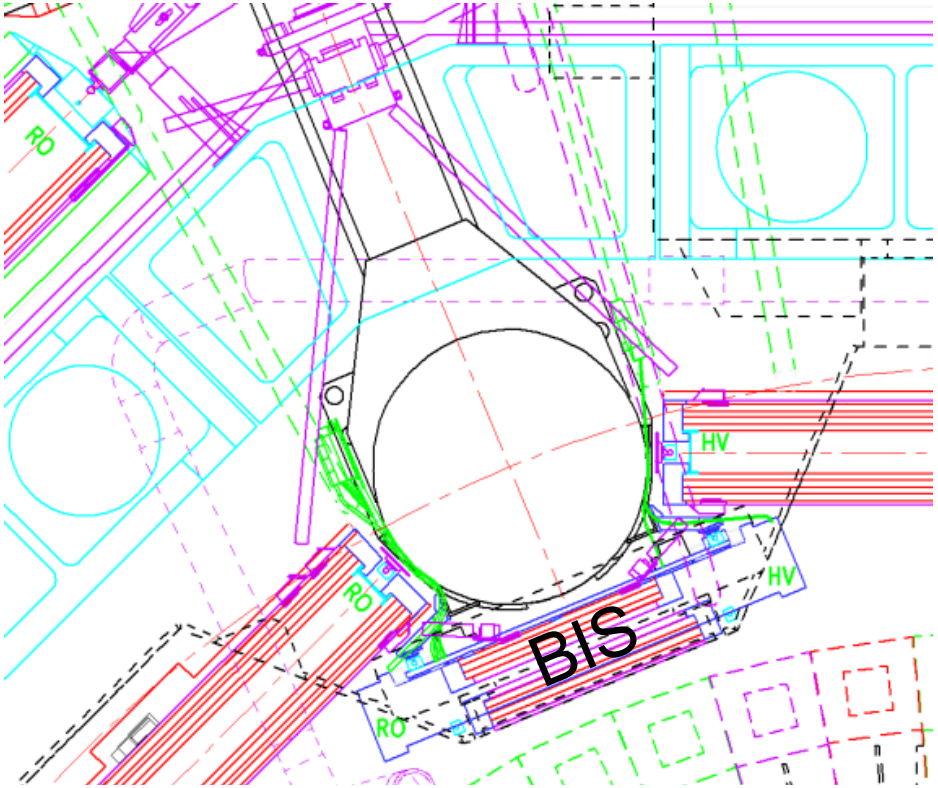
Mechanical precision

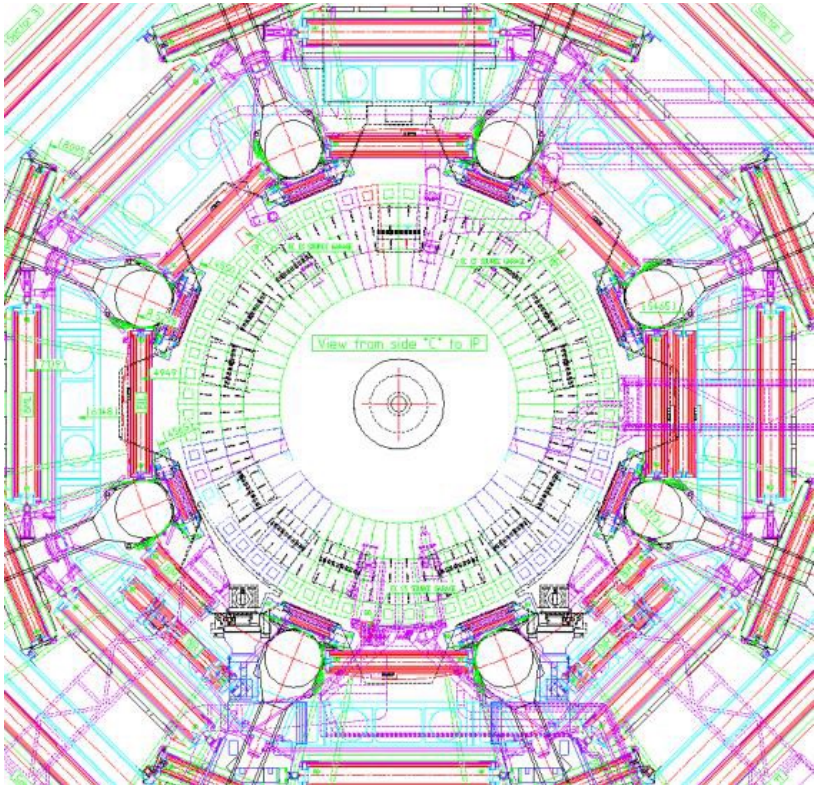
BME-A	RO side	HV side	Nominal from measurement of jigs
z-pitch [mm]	15.099 ± 0.0001	15.099 ± 0.0001	15.100
y-pitch [mm]	13.096 ± 0.001	13.086 ± 0.001	13.095 (RO) 13.085 (HV)
z-offset layers [mm]	7.553 ± 0.0001	7.551 ± 0.0001	7.550
z-distance ML [mm]	0.008 ± 0.001	0.014 ± 0.001	0
y-distance ML [mm]	135.339 ± 0.002	135.266 ± 0.002	135.345 (RO) 135.270 (HV)
RMS wire pos. z	7 µm	7 µm	20 µm
RMS wire pos. y	11 µm	8 µm	20 µm



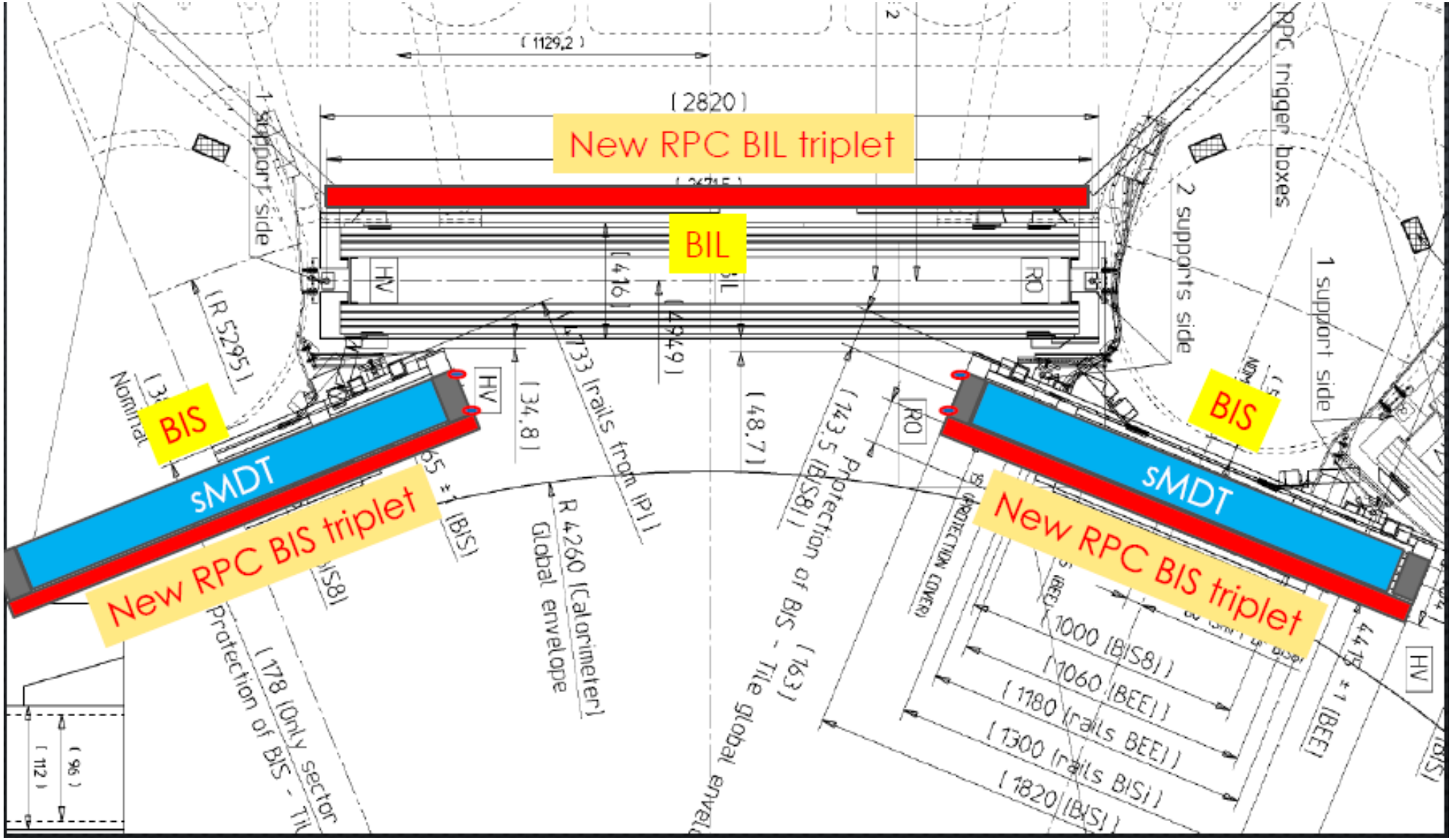
Excellent wire positioning accuracy and reproducibility from CMM measurement of endplugs immediately after construction.

MDT chambers in the current Barrel Muon Spectrometer
BIS is under the magnet coil

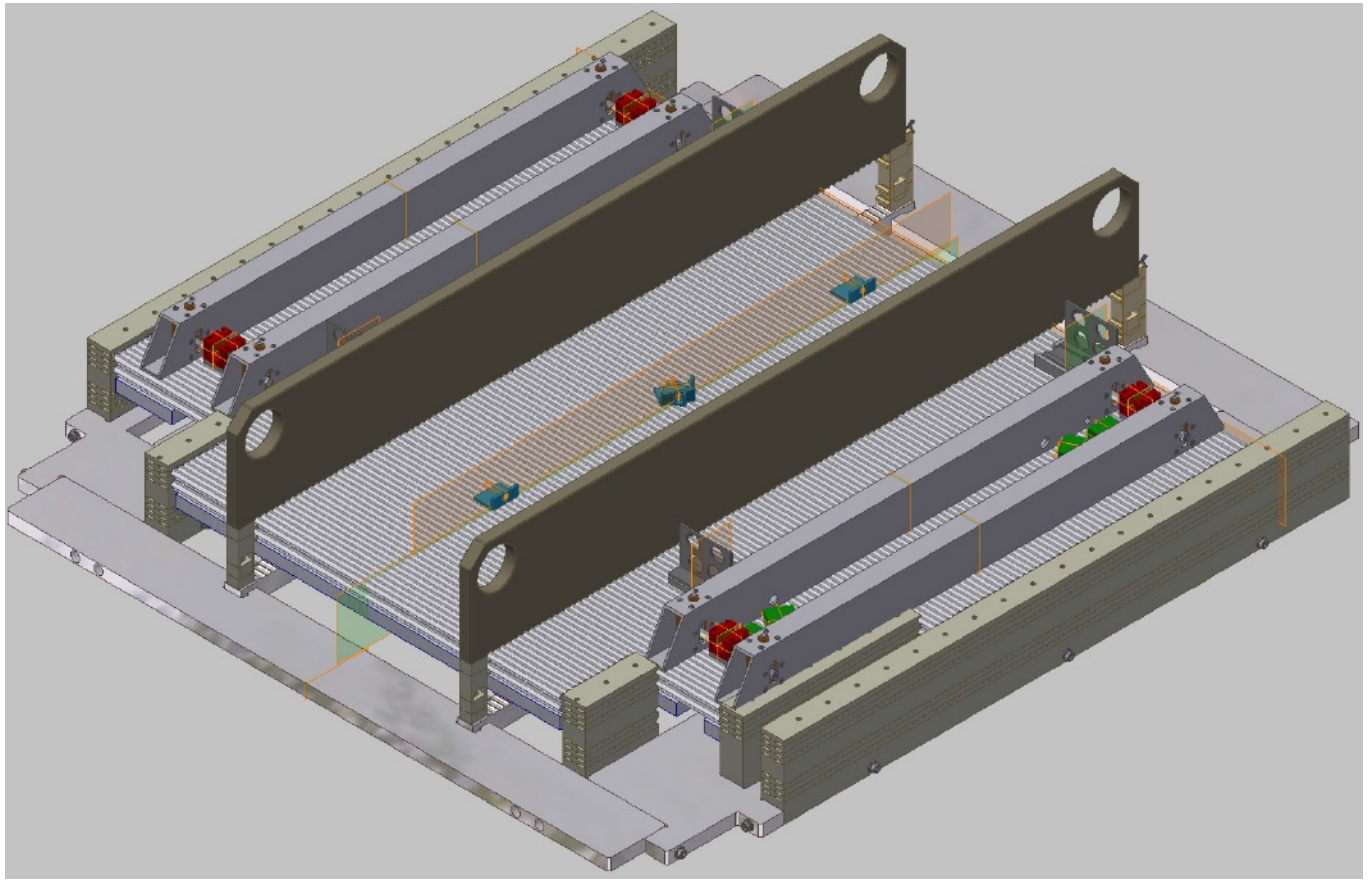




Phase 2 upgrade for barrel trigger system

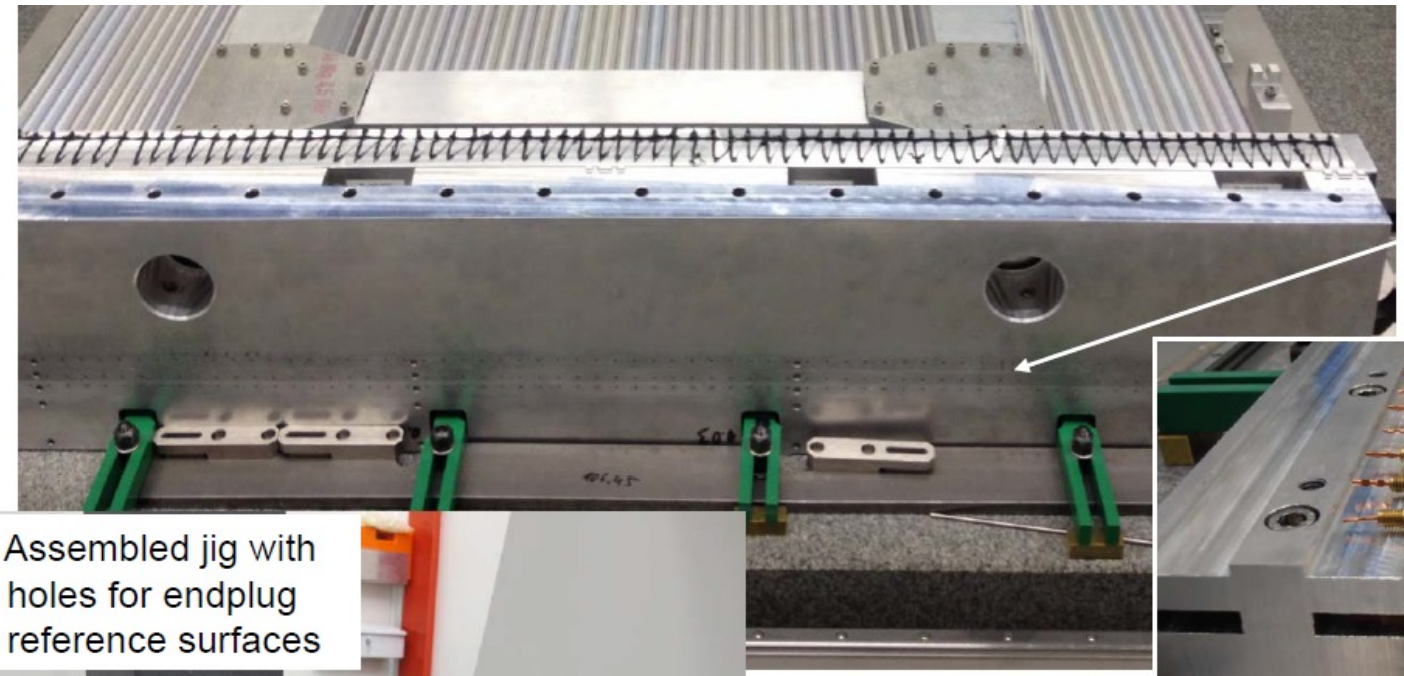


Need to build new sMDT Assembly Tooling

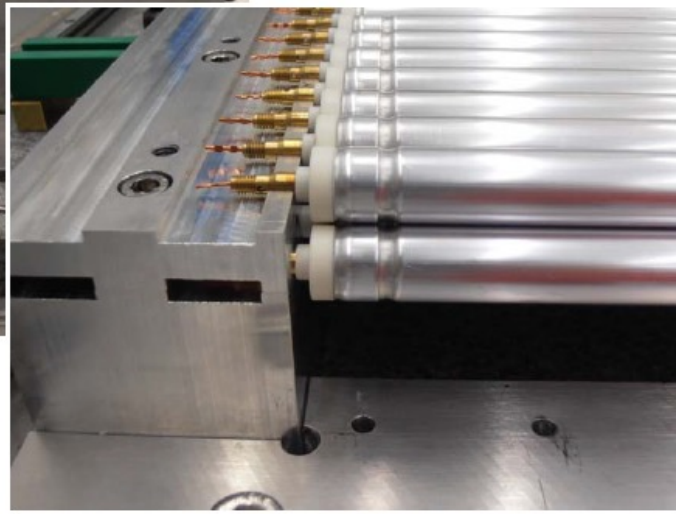


Construction of spacer frame

Chamber construction



Holes for ground pins screwed into the gaps between three adjacent tubes

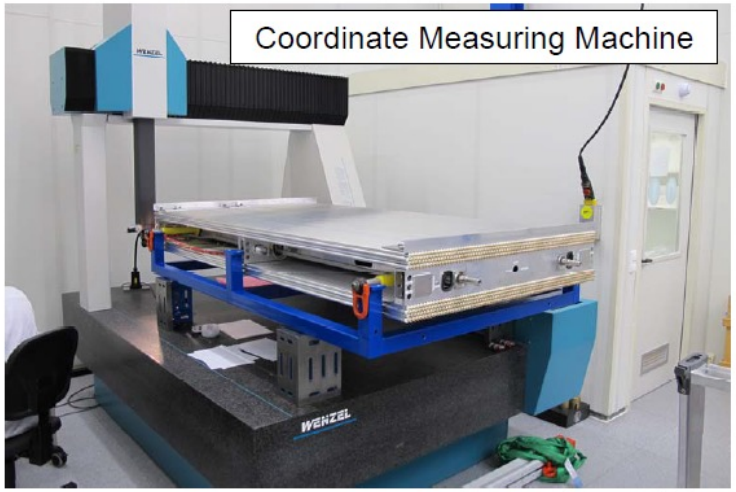


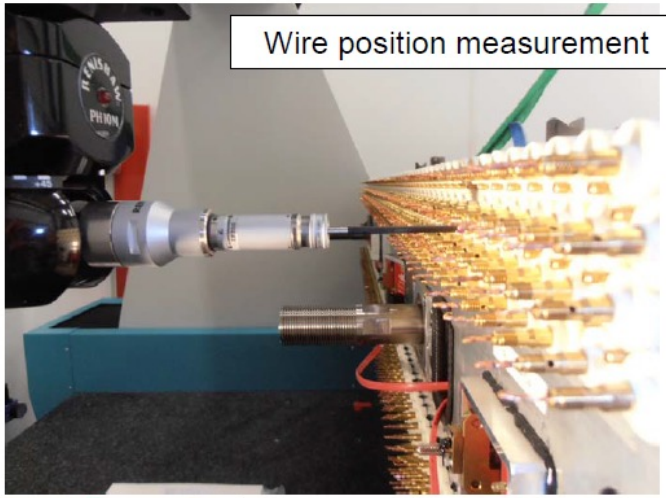
Assembled jig with holes for endplug reference surfaces

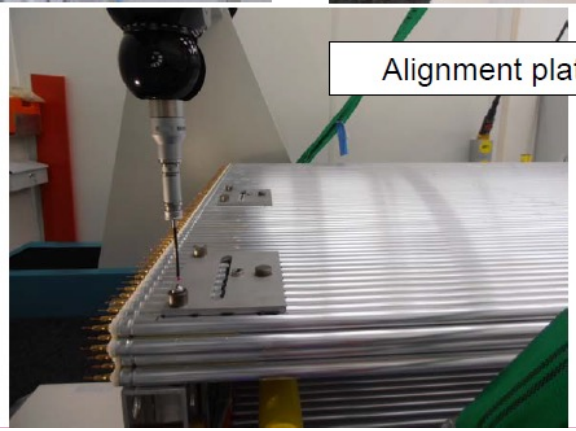
Chamber assembly:
stacking of tube and comb layers including spacer frame

⇒ glueing of a whole chamber within one working day

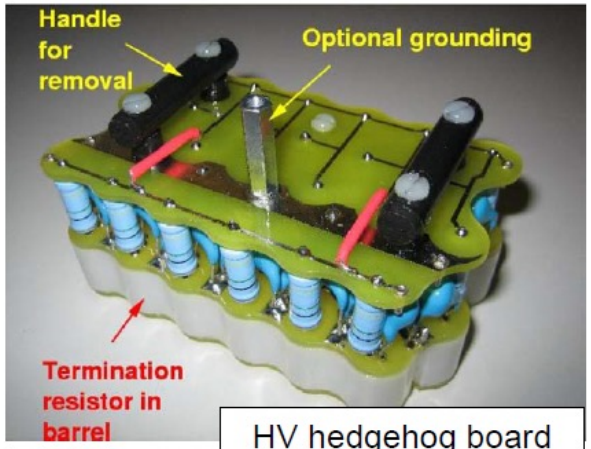
Optical QA/QC tests







HV and RO distribution boards

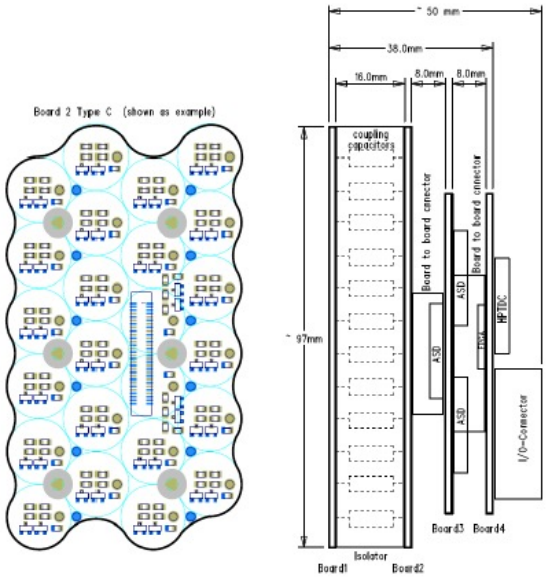


HV hedgehog board

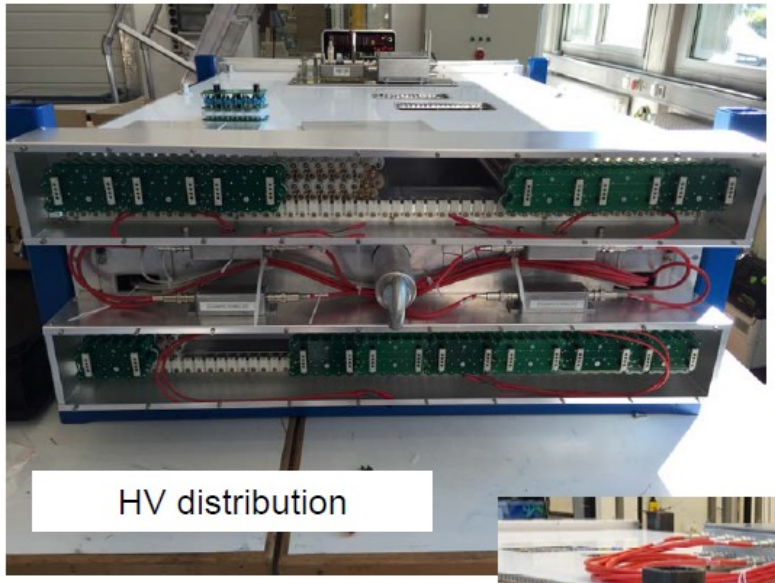

RO hedgehog and mezzanine board

sMDT HV and RO distribution boards and active readout boards (mezzanine cards) already designed and produced for BMG and BIS 7/8 chambers. Will be produced by MPI for BIS 1-6.

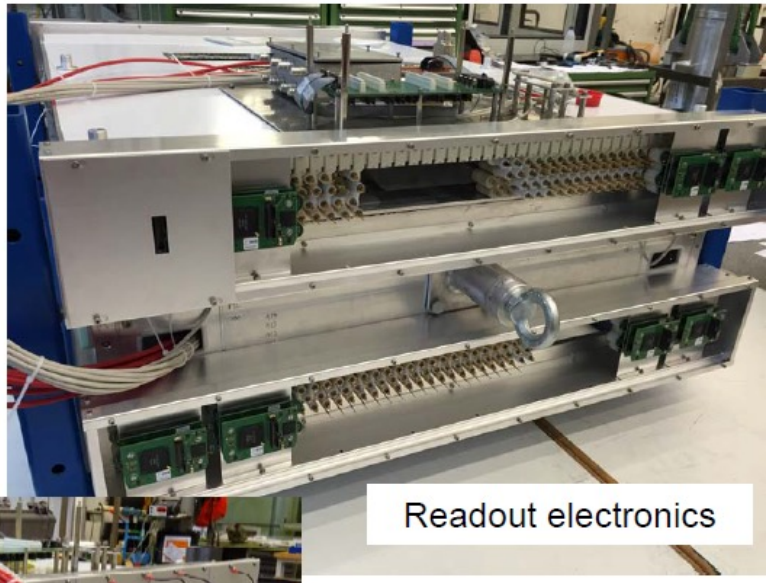
New ASD and TDC chips are under development which include MDT L0 trigger functionality.



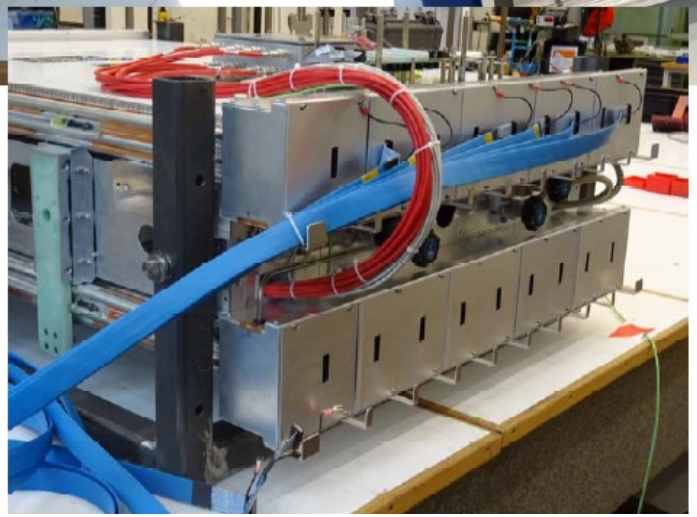
Gas system, Readout FE mounts



HV distribution



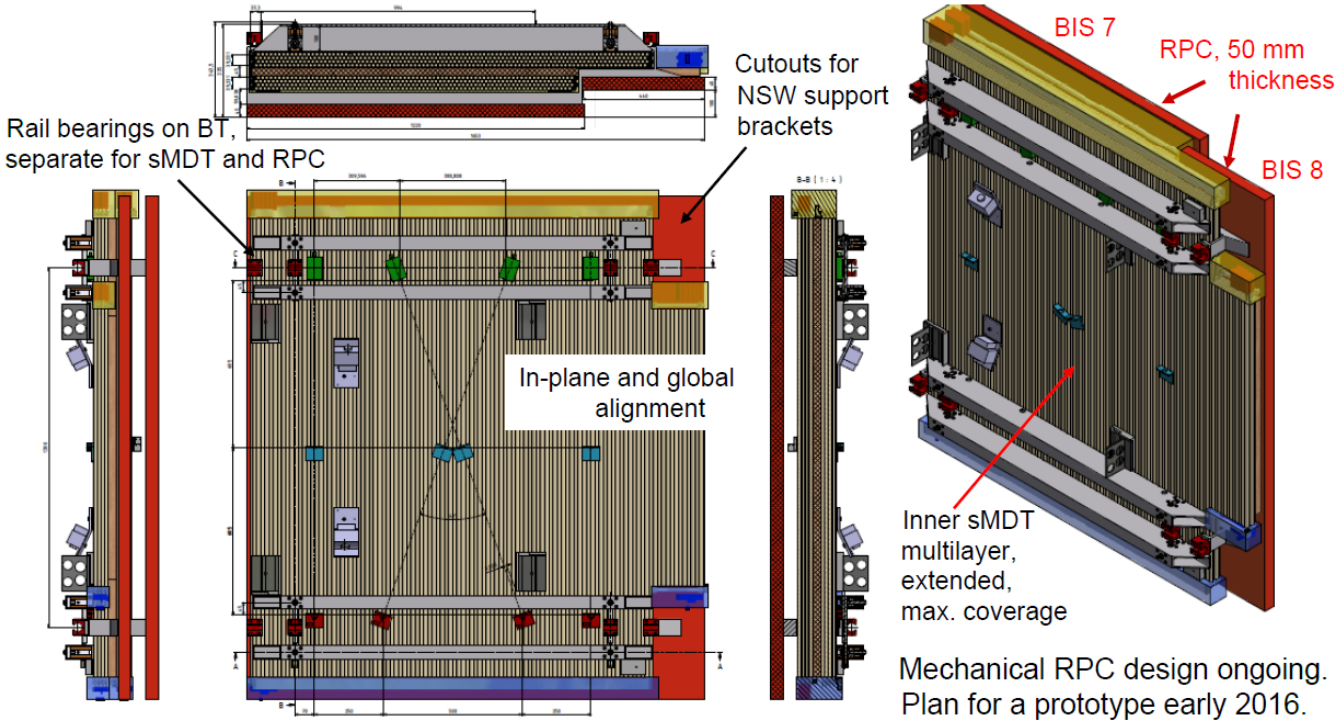
Readout electronics



Integration with RPC and Alignment system

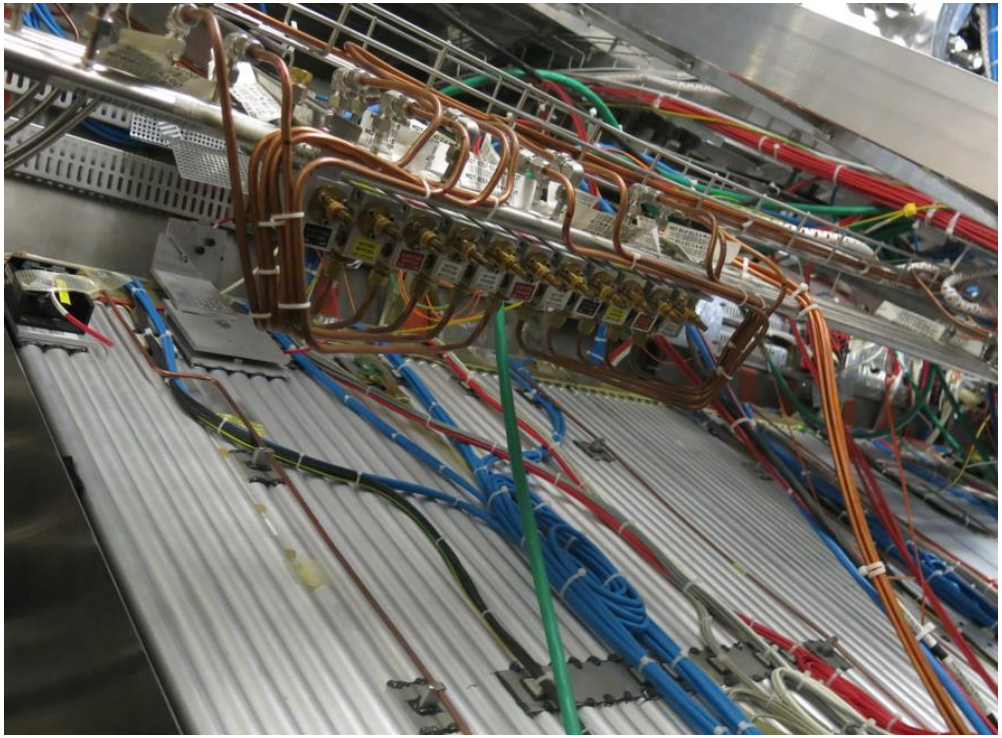
Integrated BIS 7/8 sMDT and RPC design with alignment connections to New Small Wheel.

sMDT design close to final. Model for Phase II BI layer upgrade.



Mechanical RPC design ongoing.
Plan for a prototype early 2016.

Barrel MDT chambers in Muon Spectrometer



Engineering Design

1 Feeding of wire through tube and endplugs by clean air flow w/o touching the wire piece inside the tube

2 Automated insertion of endplugs into the tube

3 Automated mechanical swaging of the endplugs into tube with tool rotating the tube

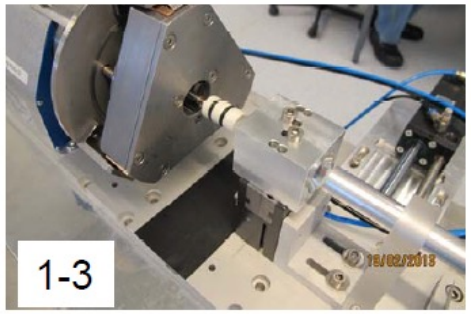
4 Automated crimping of the wire in copper crimp tubelet at one tube end

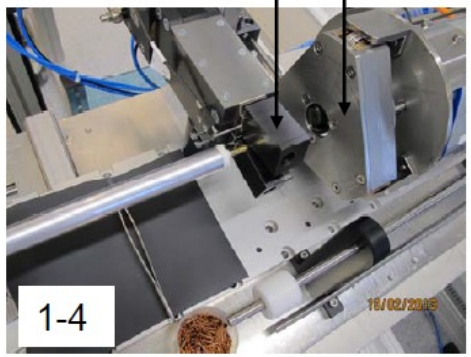
5 Automated wire tensioning and crimping at other end

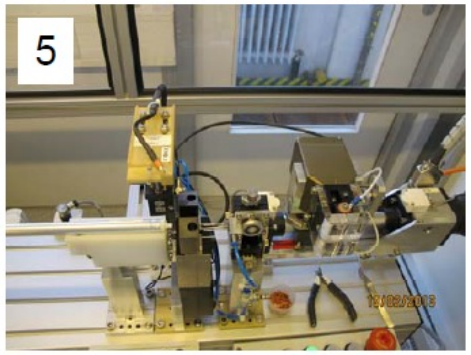
6 Automated wire tension (oscillation frequency) measurement

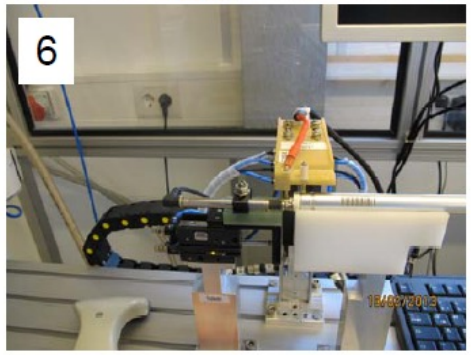
Drift tube production rate: 100 tubes/ day

by 2 technicians handling the tubes

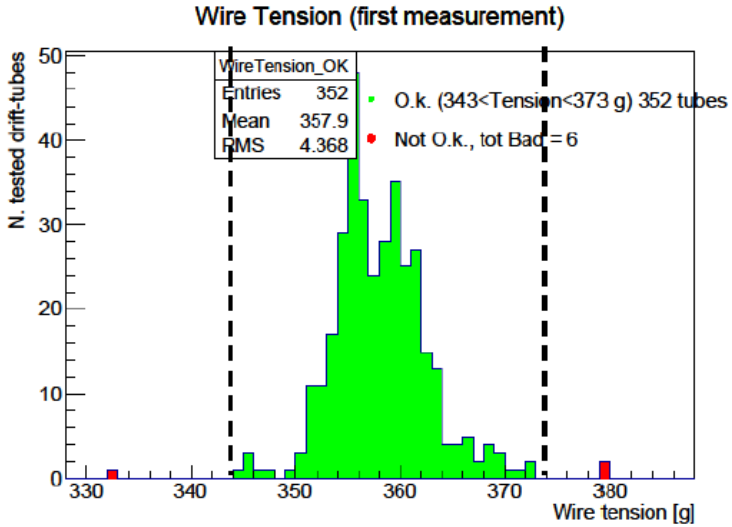


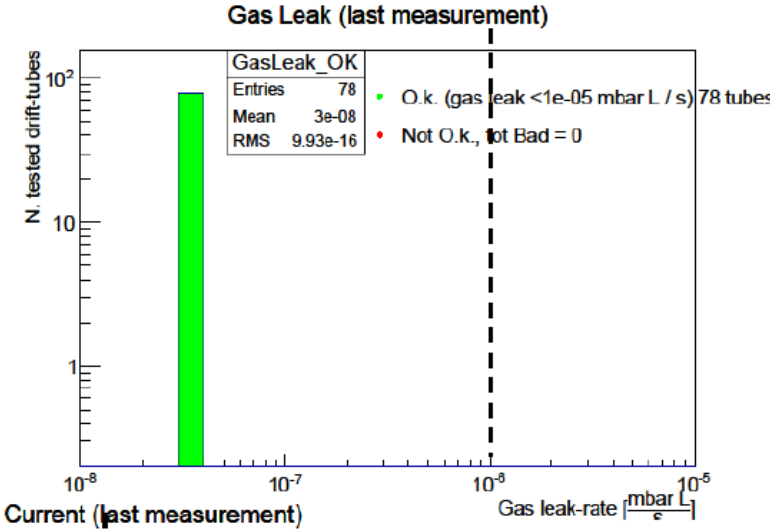


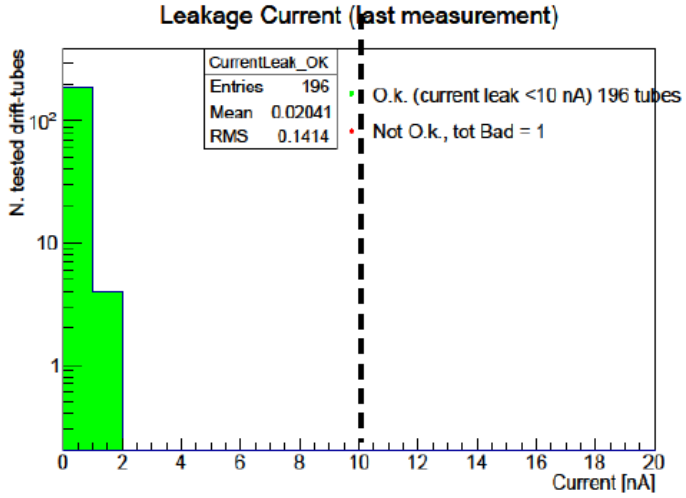




Automatised leakage current and gas leak rate measurement over night. Same quality control as for MDTs, except that there is no need for wire position measurement with new endplug design.







Experience at University of Michigan 2000-2003

Constructed 80 largest precision MDT Chambers

Constructed 32,000 long precision tubes